

DebrisSat: The New Hypervelocity Impact Test for Satellite Breakup Fragment Characterization

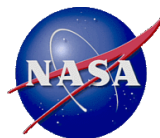
Heather Cowardin, Ph.D.

Optical Measurements Lead

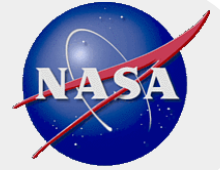
Orbital Debris Research & Science Operations

University of Texas at El Paso – Jacobs JETS Contract

In support of the NASA Orbital Debris Program Office



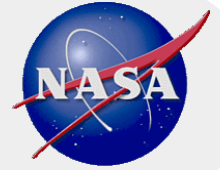
Presented at 33rd IADC Meeting, Houston, 30 March – 2 April 2015.



The DebrisSat Team

- **NASA Orbital Debris Program Office (ODPO)**
 - Co-sponsor, project and technical oversight, data collection, data analyses, NASA model improvements. *J.-C. Liou, J. Opiela, H. Cowardin, P. Krisko, et al.*
- **AF Space and Missile Systems Center (SMC)**
 - Co-sponsor, technical oversight *T. Huynh, D. Davis, et. al.*
- **The Aerospace Corporation**
 - Design of DebrisSat, design/fabrication of DebrisLV, data collection, data analyses, DoD model improvements: *M. Sorge, C. Griffice, P. Sheaffer, et al.*
- **University of Florida (UF)**
 - Design/fabrication of DebrisSat, data collection, fragment processing and characterization: *N. Fitz-Coy and the student team*
- **AF Arnold Engineering Development Complex (AEDC)**
 - Hypervelocity impact tests: *R. Rushing, B. Hoff, M. Nolen, B. Roebuck, D. Woods, M. Polk, et al.*

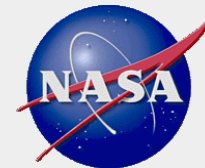




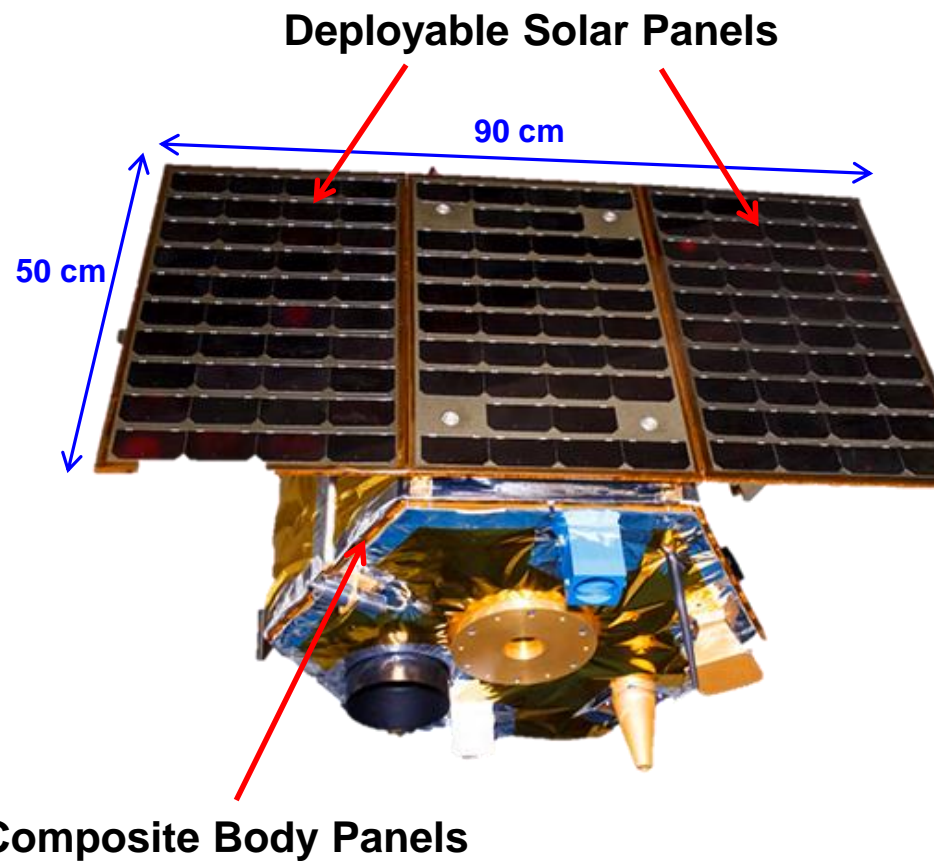
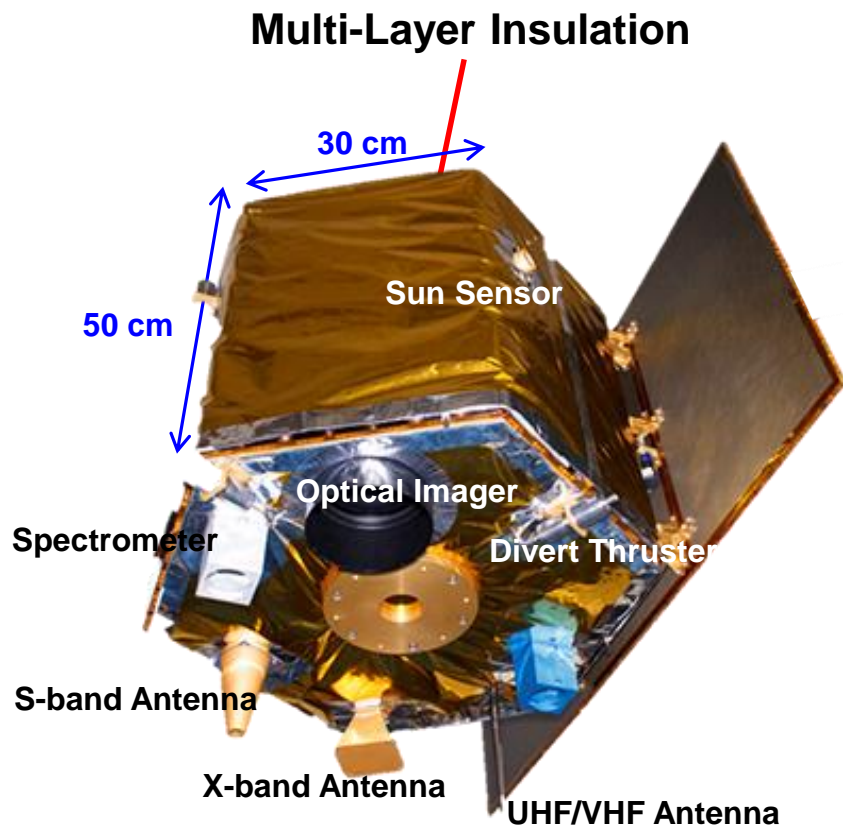
Background

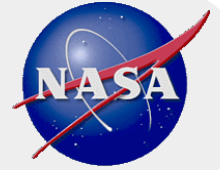
To replicate a hyper-velocity fragmentation event using modern-day spacecraft materials and construction techniques to better improve the existing DoD and NASA breakup models

- DebrisSat is intended to be representative of modern LEO satellites
 - Major design decisions were reviewed and approved by Aerospace subject matter experts from different disciplines
- DebrisSat includes 7 major subsystems
 - Attitude determination and control system (ADCS), command and data handling (C&DH), electrical power system (EPS), payload, propulsion, telemetry tracking and command (TT&C), and thermal management
 - To reduce cost, most components are emulated based on existing design of flight hardware and fabricated with the same materials
- A key laboratory-based test, Satellite Orbital debris Characterization Impact Test (SOCIT), supporting the development of the DoD and NASA satellite breakup models was conducted at AEDC in 1992
 - Breakup models based on SOCIT have supported many applications and matched on-orbit events reasonably well over the years



Design

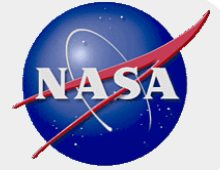




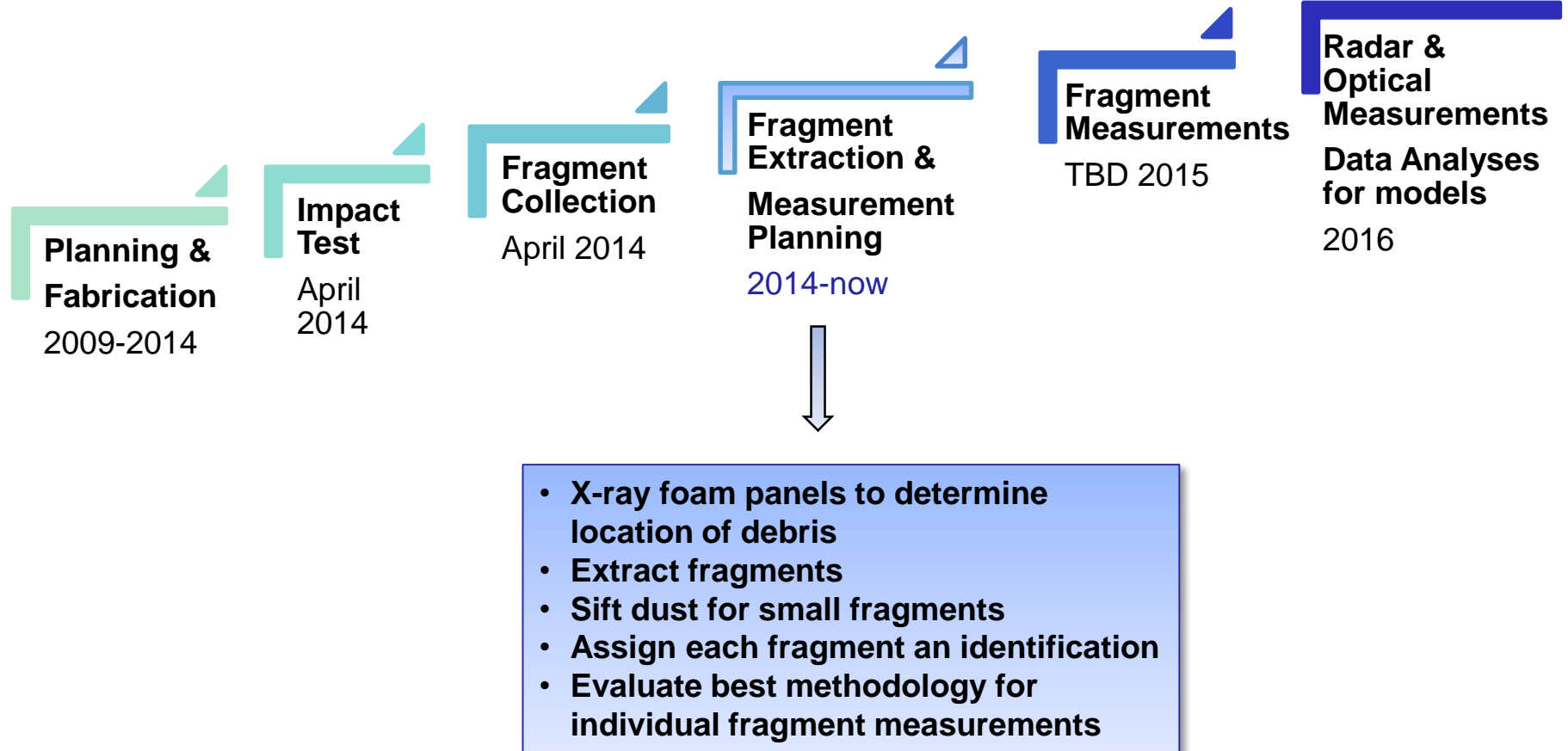
DebriSat versus SOCIT/Transit

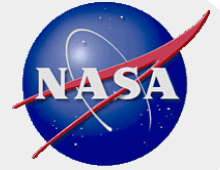
- DebriSat has a modern design and is 63% more massive than Transit
- DebriSat is covered with MLI and equipped with solar panels

| | SOCIT/Transit | DebriSat |
|---|--------------------------|--------------------------|
| Target body dimensions | 46 cm (dia) × 30 cm (ht) | 60 cm (dia) × 50 cm (ht) |
| Target mass | 34.5 kg | 56 kg |
| MLI and solar panel | No | Yes |
| Projectile material | Al sphere | Hollow Al cylinder |
| Projectile dimension/mass | 4.7 cm diameter, 150 g | 8.6 cm × 9 cm, 570 g |
| Impact speed | 6.1 km/sec | 6.8 km/sec |
| Impact Energy to Target Mass ratio (EMR) | 78 J/g (2.7 MJ total) | 235 J/g (13.2 MJ total) |



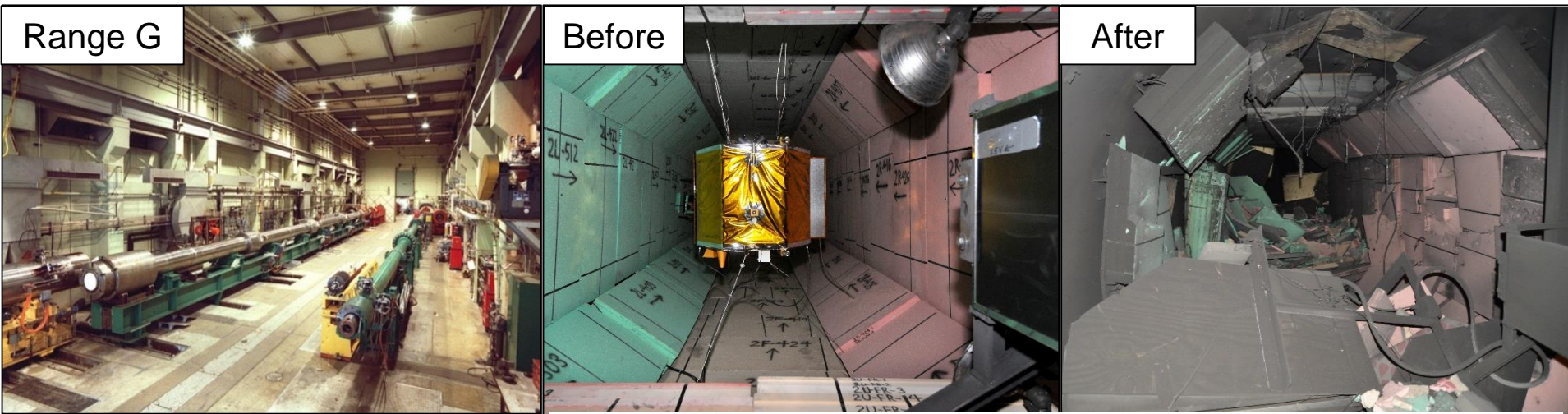
DebrisSat Stages



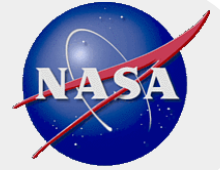


Impact Test

- **AEDC's Range-G operates the largest two-stage light gas gun in the U.S.**
- **Standard diagnostic instruments include X-rays, high-speed Phantom cameras, and lasers**
 - With additional IR cameras, piezoelectric sensors, and witness plates
- **Low-density polyurethane foam panels are installed inside target chamber to “soft catch” fragments**

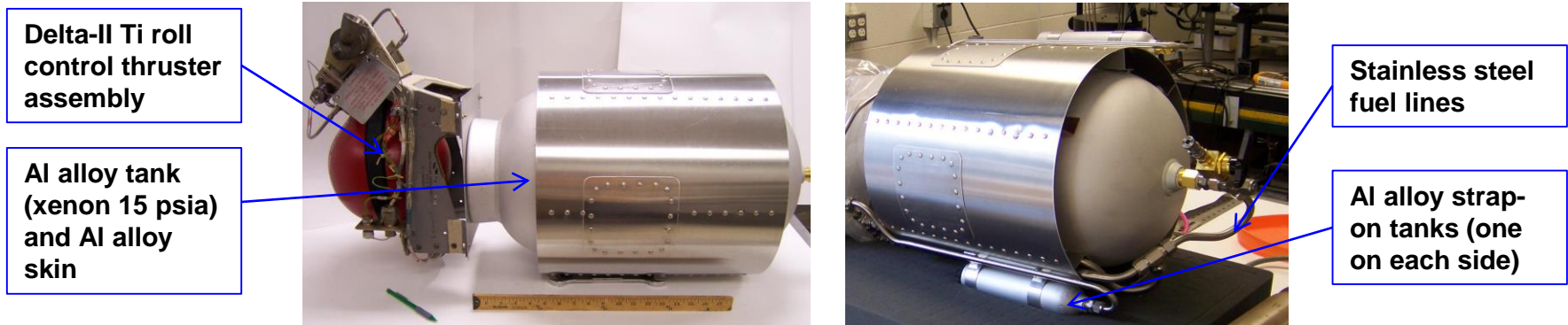


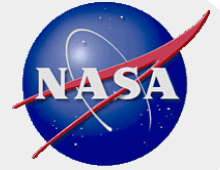
Target chamber before and after impact (10' × 20').



Pre-test Shot

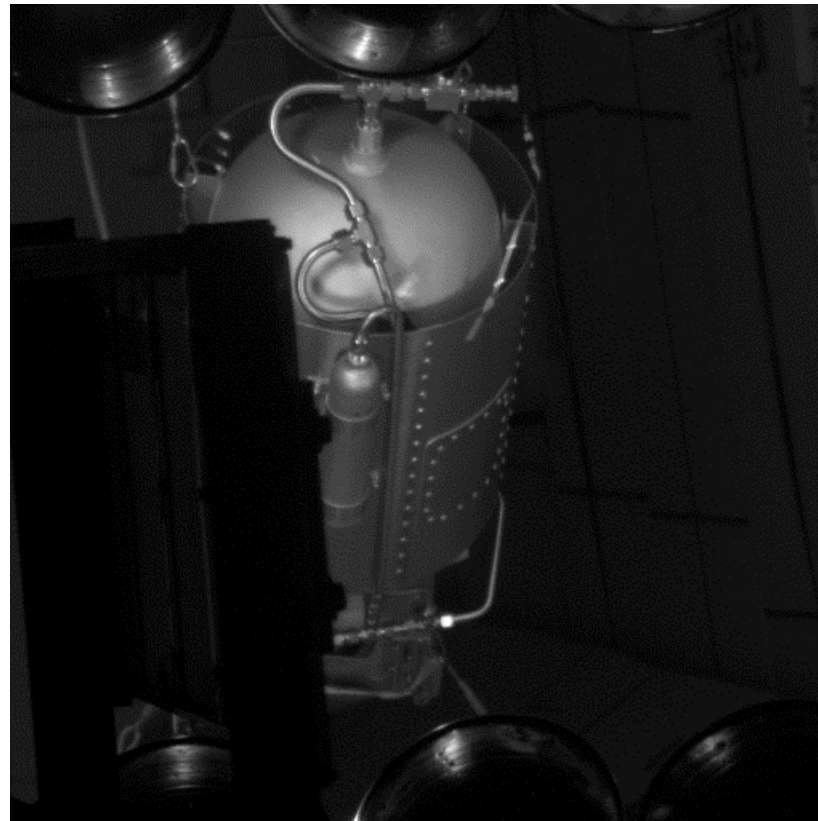
- **To further increase the benefits of the project, Aerospace built a target resembling a launch vehicle upper stage (“DebrisLV”) for the pre-test shot**
 - DebrisLV: 17.6 kg, body dimensions ~ 88 cm (length) × 35 cm (diameter)
 - Test conditions were identical to the impact on DebrisSat (facility setup, projectile, impact speed, *etc.*)
- **Pre-test shot was successfully conducted on April 1st**
 - Projectile impacted DebrisLV at 6.9 km/sec and completely fragmented the launch vehicle
 - Fragments and soft catch foam panels/pieces were collected in boxes on 19 pallets for shipment

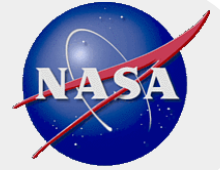




DebrisLV Impact Sequences

- **DebrisLV shot was successfully conducted on April 1st**
 - DebrisLV was impacted by 598 g projectile at 6.9 km/sec and completely fragmented the target



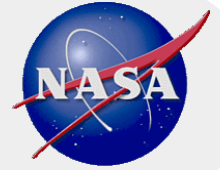


DebrisSat Impact Sequences

- **DebrisSat shot was successfully conducted on April 15th**
 - DebrisSat impacted by 570 g projectile at 6.8 km/sec and completely fragmented the target



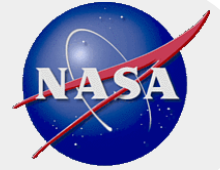
DebrisSat Laboratory-Based Hypervelocity Impact Test



Post-Impact Fragment Collection

- **After impact, all intact foam panels, broken foam pieces, loose fragments, and dust were carefully collected, documented, and stored**
 - 41 pallets of ~2 m × 2 m × 2 m boxes were packed
 - Estimated ≥ 2 mm DebrisSat fragments are on the order of 85,000
 - Estimated > 40,000 pieces have been collected so far





Fragment Extraction & Measurement Planning

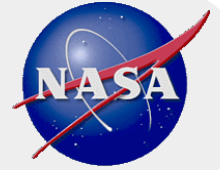
- Conduct X-ray scanning of foam panels/pieces to identify locations of ≥ 2 mm fragments
- Extract ≥ 2 mm fragments from foam panels/loose pieces/dust
- Recover at least 90% of the total DebrisSat mass from the fragments



Sifting thru dust for 2mm fragments

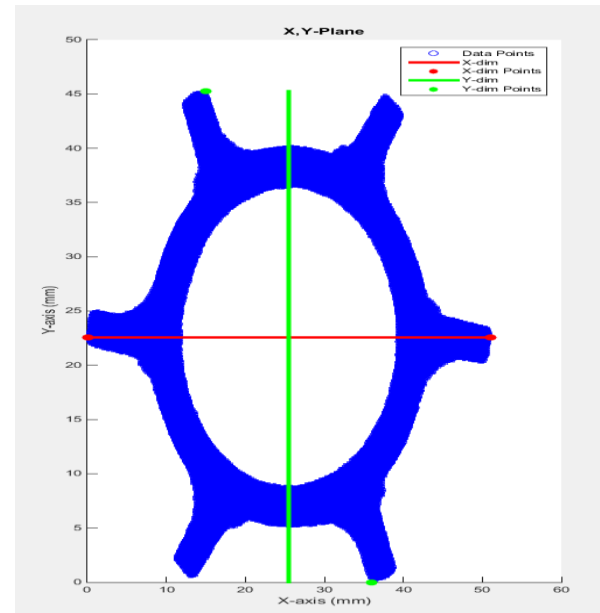


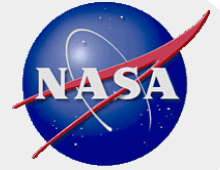
X-ray image projected on panel to identify debris



Fragment Extraction & Measurement Planning

- **Measure individual fragments**
 - Primary: dimensions with associated 3D plots, mass, shape, material estimate, and digital pictures all stored in a accessible database.
 - Secondary: effective density, material specific
 - Investigating new ways to measure the size of an object without using “human-in-the-loop” methodologies: *Space Carving*
- **Obtain 3D scanning data for selected fragments**
 - Cross-sectional area, Area-to-Mass ratio, bulk density

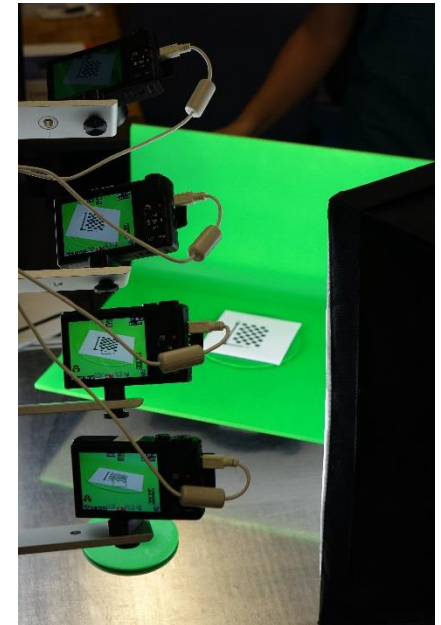


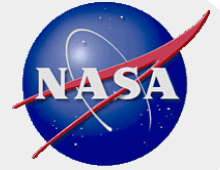


Space Carving

Space Carving is a technique used to characterize a 3D scene, in the absence of a priori geometric information, based on N arbitrarily position cameras and known viewpoints

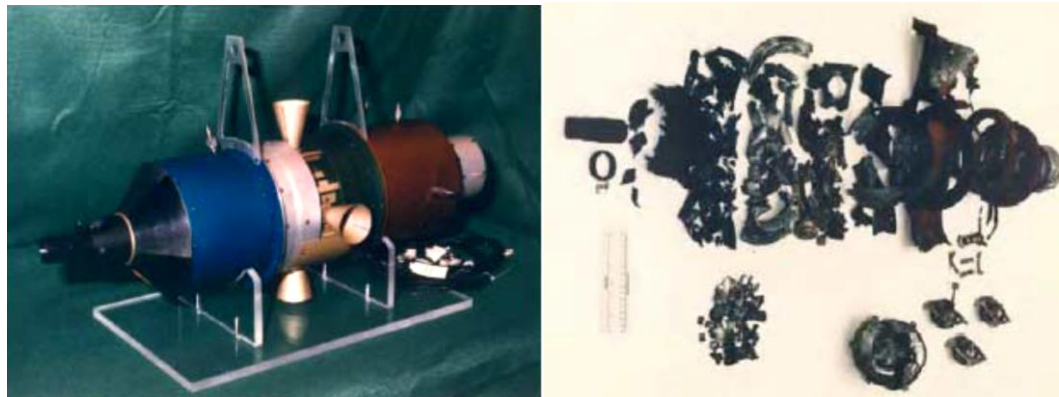
- **Set-up:**
 - Turntable mounted on a stepper motor
 - Optically and physically continuous background within camera's field of view (FOV)
 - Multiple cameras and various altitudes to image different aspect angles of object
- **Procedure:**
 - Acquire calibration image data for each camera from known object/calibration panel
 - At each rotation a set of images are collected from each camera
 - Images are stitched together to recreate 3D image
- **Analysis**
 - Initial test measurements prove successful in comparison to caliper measurements and 3D point cloud size measurements with $< 1\%$ error
 - Time to complete analysis from imaging to data product is within minutes versus hours

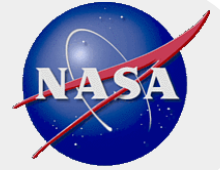




Applied Measurements

- **Laboratory radar and optical measurements will be performed on a subset of fragments to provide a better understanding of the data products from orbital debris acquired from ground-based radars and telescopes**
- **Radar will provide a radar cross section at a specified frequency, while optical will provide a newly defined term, optical cross section**
- **The current NASA Size Estimation Model is purely based on radar measurements from a hypervelocity impact of dated simulated spacecraft. The data from DebrisSat will be used to update the NASA Radar Size Estimation Model with more modern materials, as well as include optical measurements into the model**





Applied Measurements

- **Current optical measurements assume a range, albedo, and phase function (how the intensity changes as a function of phase angle)**
 - Laboratory optical photometric measurements (ie, BRDF) will help refine these assumptions to better provide a size estimate comparable to radar
 - Laboratory spectral measurements will also be used to analyze albedo changes of the fragments provided the baseline (pre-impact measurements) and post-impact (material darkening, *etc.*)
 - A subset of the fragments will also be sent to space environment effect chambers to study to how the optical properties of materials change due to space weathering
- **Radar/Optical measurements are slated to start 2016, contingent on available resources**